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Estimating an Augmented Cost Progress Function for Tactical Aircraft

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Task Objective

- "Develop databases and methods for estimating the development and production costs of next generation fighter/attack aircraft"
- For high volume aircraft like the JSF, differing progress curve parameters will have a large effect on estimated costs

Model Architecture

- Framework for data and estimating relationships
- Detail sufficient to capture effects of new technology/environment
  - Direct Costs
    - WBS levels 3-5
      - e.g. Airvehicle.Airframe.Structures.Wing
    - By function
      - Labor hours by category; modeled at T1/T100
      - Materials/purchased equipment dollars
  - Indirect costs
    - Fixed and variable prime contractor overhead

Cost Progress Function Overview

- Interest in testing the effects on cost progress of phenomena beyond cumulative quantity
  – Investment/capital intensity
  – Production rate/fixed cost effects
  – Break-points/two and three-piece curves
  – Modifications/model changes/weight growth
- These effects would be important in modeling JSF costs
  – Increased automation/application of new technologies
  – High production rates
  – Large production quantity
- Ultimate goal is to unify aircraft and plant-level modeling

Approach to Cost Progress Function Estimation

- Use existing data to estimate augmented learning curves
  - Multi-Aircraft Cost Data & Retrieval (MACDAR) database
  - Manufacturing labor
  - F-14A, F-15A/B/C/D/E, F-16A/B/C/D, F-18A/B/C/D, AV-8B
    - Includes large production runs, high rates and model changes
    - Aircraft are built in plants where plant-wide financial data are available
- Estimate generalized cost progress function
  - Cost data for 5 programs is pooled
  - Slope and other parameters are the same across programs
  - Dummy variables distinguish T1 differences
  - Nonlinear estimation

Effects Included

- Capital Intensity
  - Change in plant-wide capital/labor ratio over life of program
    - Metric for the *i*th program, *j*th lot
      - $[\Delta K/L]_{ij} = (K/L)_{ij} - (K/L)_{i1}$

    $(K/L)_{i1}$ is K/L associated with building the first lot of the jth program
  - Effect on cost progress; no estimation of K/L effects on T1
    - to be included later
- Segmented progress function; two-piece curve breaking a unit 400.
- Weight growth; weight growth factor - T1 adjustment
  - Allows use data from complete production run

Production rate and fixed cost effects tested, but not statistically significant

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Preferred Model Specification

- Lot $Cost_{ij} = q_{ij}(T1_i Q_{ij}^{\beta_1})\ WGF_{ij}^{\beta_2}\ \beta_3^{[\Delta K/L]_{ij}}$, where
  - Lot $Cost_{ij}$ is the lot cost in manufacturing hours for the jth lot of the ith aircraft model
  - q_{ij} is the lot quantity for the jth lot of the ith aircraft model
  - $T1_i$ is the first unit cost for the ith aircraft model
  - Q_{ij} is the cumulative quantity for the jth lot of the ith aircraft model calculated at the lot midpoint
  - $\beta_1; Q_{ij} < 400 \neq \beta_1; Q_{ij} > 400$
  - WGF_{ij} is the weight growth factor for the jth lot of the ith aircraft model, where

    WGF_{ij} = airframe unit $weight_{ij}$/ airframe unit $weight_{i1}$
  - $\beta_3^{[\Delta K/L]_{ij}}$ relates change in capital intensity to change in cost
    - Matched plant-wide K/L time-series to programs/lots
    - $\beta_3 < 1$; percentage change in cost per unit Δ K/L = $\beta_3 - 1$

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Estimation Results: Preferred Specification

Paramter Estimates

T1, K Hours	w/o K/L	with K/L
F-14		
F-15		
F-16		
F/A-18		
A/V-8B		

Other parameters		
Slope, Q <400	**77.0%**	**77.3%**
Slope, Q >400	**91.7%**	**93.5%**
Weight Growth B	3.36	3.60
ΔK/L B		0.9979

Model Fit and Hypothesis Tests

	w/o K/L	with K/L
R^2	0.970	0.974
Standard Error	0.084	0.080

Hypothesis Tests		
LC B; Q>400 = LC B; Q>400		
Hypothesis test for equal Bs		
p level	<.001	<.001
WGF B=0		
T ratio	6.4	7.6
p level	<.001	<.001
K/L B=1		
T ratio		2.4
p level		0.021

Business Case
Sanity Check on ΔK/L Effect

- What is the payoff period for a an increase in K/L?
  - Increase in K/L results in a decrease in labor hours
  - Given some representative staff year cost, how long will it take for an investment to pay for itself?
- Analysis (constant 1995 dollars)
  - Increase K by 20K per direct manufacturing worker
    - Decrease labor hours by 4.3%
  - Savings in staff years
    - Value of staff year
      - 2000 hours/year X $40/hour (wage rate + variable overhead) = 80k/year
    - Savings = 4.3% X $80K = $3.5K/year
  - Payoff period = $20K/$3.5K = 6.1 years

Alternate Model Specifications

- Fixed cost specification:

  $\text{Lot Cost}_{ij} = q_{ij}(T1_i Q_{ij}^{\beta_1})\ WGF_{ij}^{\beta_2}\ \beta_3^{[\Delta K/L]_{ij}} + T1_i\beta_4$

  b_4 is not statistically significant

- "Rate slope" specification:

  $\text{Lot Cost}_{ij} = q_{ij}(T1_i Q_{ij}^{\beta_1}\ q_{ij}^{\beta_5})\ WGF_{ij}^{\beta_2}\ \beta_3^{[\Delta K/L]_{ij}}$

  Where q is lot quantity; *b_5 is not statistically significant*

- "Divergence from optimal rate" specification:

  $\text{Lot Cost}_{ij} = q_{ij}(T1_i Q_{ij}^{\beta_1})\ WGF_{ij}^{\beta_2}\ \beta_3^{[\Delta K/L]_{ij}} + \beta_6\,(q_{ij} - R_i^*)^2$

  Where R_i^* is the optimum lot quantity for the ith aircraft model

  Estimates of R_i^* are unstable and often counterintuitive:

	Peak rate	Ri*
F-14	86	78
F-15	135	31
F-16	219	26
F/A-18	146	117
A/V-8B	40	90

Integrating Component CERs with the Cost Progress Function

- Build on T1 *(or T100)* component-level CERs
  - $T1_{ik}$ is the T1 cost for the kth component of the ith aircraft type
  - $T1hat_{ik}$ is the expected value of $T1_{ik}$ given some set of physical/engineering parameters (CER predictions)
- Part of the error in estimates of $T1_{ik}$ may be due to economic parameters:
  - $T1_i = \Sigma_k T1hat_{ik}\, \mathbf{f}[K/L]_{i1}$ (*or* $T1_i = AS_k\, T100hat_{ik}\, \boldsymbol{f}[K/L]_{i1}$)
  - $\Sigma_k T1hat_{jk}$ is an instrumental variable for the technical difficulty of building the aircraft - non-stochastic regressor
  - Include $\Sigma_k T1hat_{ik}$ variable when estimating cost progress function
    - Estimate single intercept instead of multiple T1s

Approach to Overhead Costs

- Goal is to unify aircraft and plant-level modeling
- Annual plant-wide overhead has been modeled as a function of direct labor and capital
  - $OH_t = \alpha + \beta_1 DL_t + \beta_2 K_t$
- This model can be linked to the cost progress function through the capital and labor variables
- Additional information is needed to make estimates
  - Business in plant other than JSF
  - Estimates of capital
    - K is exogenous
      - K/L is then estimated simultaneously with direct manufacturing labor

      or
    - K/L is exogenous
      - K is then estimated using estimates of direct labor